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I HEREBY CERTIFY that annexed hereto is a true copy of documents filed in connection with the following patent application:

Application No.	S2002/0709
Date of Filing	2 September 2002
Applicant	INTUNE TECHNOLOGIES LIMITED, an Irish Company of 9c Beckett Way, Park West Business Park, Nangor Road, Dublin 12, Ireland.

Dated this 4 day of September 2003.

Clare O'Reilly

An officer authorised by the
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S02071

Form No.1

REQUEST FOR THE GRANT OF A PATENT

Patents Act, 1992

The Applicant(s) named herein hereby request(s)

the grant of a patent under Part II of the Act

☒ the grant of a short term patent under Part III of the Act on the basis of the information furnished hereunder

1. Applicant(s)

Name: **INTUNE TECHNOLOGIES LIMITED**

Address: **9c Beckett Way, Park West Business Park, Nangor Road, Dublin 12, Ireland**

Description/Nationality : **an Irish Company**

2. Title of Invention:

METHOD FOR OPTIMISING NON-LINEAR LASER CONTROL EFFECTS

3. Declaration of Priority on basis of previously filed application(s) for same invention (Sections 25 & 26)

Previous Filing Date	Country in or for which filed	Filing No.

4. Identification of Inventor(s):

Name(s) of person(s) believed by applicants to be the inventor(s) address:

5. Statement of right to be granted a patent (Section 17(2) (b))

Date of assignment from inventors:

6. Items accompanying this Request - tick as appropriate

(i) ☒ prescribed filing fee

(ii) ☒ specification containing a description and claims
specification containing a description only
☒ Drawings to be referred to in description or claims

(iii) An abstract

(iv) Copy of previous application(s) whose priority is claimed

(v) Translation of previous application whose priority is claimed

(vi) Authorisation of Agent (this may be given at 8 below if this request is signed by the applicant(s))

7. Divisional Application(s)

The following is applicable to the present application which is made under Section 24 -

Earlier Application No:
Filing Date:

8. Agent

The following is authorised to act as agent in all proceedings connected with the obtaining of a patent to which this request relates and in relation to any patent granted -

Name	Address
TOMKINS & CO.	**5 Dartmouth Road, Dublin 6.**

9. Address for Service (if different from that at 8)

TOMKINS & CO., at their address as recorded for the time being in the Register of Patent Agents.

Signed Name(s):
by:
Capacity (if the applicant is a body corporate):

Date: **2 September 2002**

AUTO3114

Title

Method for optimising non-linear laser control effects.

Field of the Invention

The invention relates to tuneable lasers, particularly to a multi section laser diode that can be switched between different wavelengths or frequencies and more particularly to a method adapted to compensate for variations in tuning efficiency and power of a laser.

Background to the Invention

Multi section laser diodes are well known in the art and can be switched between different wavelengths. Typically the diode is calibrated at manufacture to determine the correct control currents that should be applied to the laser so as to effect the desired output frequencies from the laser.

One of the first known multi-section laser diodes is a three-section tuneable distributed Bragg reflector (DBR) laser. Other types of multi-section diode lasers are the sampled grating DBR (SG-DBR), the superstructure sampled DBR (SSG-DBR) and the grating assisted coupler with rear sampled or superstructure grating reflector (GCSR). A review of such lasers is given in *Jens Buus, Markus Christian Amann, "Tuneable Laser Diodes" Artect House, 1998 and "Widely Tuneable Semiconductor Lasers" ECOC'00. Beck Mason.*

Figure 1 is a schematic drawing of a DBR 10. The laser comprises of a Bragg reflector sections 2 with a gain or active section 6 and phase section 4. An anti-reflection coating 9 is sometimes provided on the front and/or rear facets of the chip to avoid facet modes. The Bragg

reflector take the form of Bragg gratings 5. The pitch of the gratings of the Bragg reflector vary slightly to provide a Bragg mode which moves in frequency through varying the current supplied to these sections. The optical path length of the cavity can also be tuned with the phase section, for example by refractive index changes induced by varying the carrier density in this section. A more detailed description of the DBR and other tuneable multi-section diode lasers can be found elsewhere *Jens Buus, Markus Christian Amann, "Tuneable Laser Diodes" Artect House, 1998.*

As detailed above such tunable semiconductor lasers contain sections where current is injected to control the output frequency, mode purity and power characteristics of the device. Various applications in telecommunications/sensor fields require that the laser can operate at points in a predetermined frequency/wavelength grid; moreover many applications require the power output of the device to be within a defined tolerance for each operating point, and in general, the operating points must be distanced from mode jumps and have high side-mode suppression. In order to provide lasers for such applications, each individual device must be characterised to the desired specification, so there is a corresponding need for a system or algorithm to map the output of the laser over a range of operating currents. For characterisation of lasers in production environments, such a system must also be fast, reliable and automated.

The rate of change of the output frequency of the tunable laser for a given change in current is called the tuning efficiency of the laser. This parameter has the characteristic that it is not constant and tends to saturate at higher input currents. This variation can be

quite considerable (greater than an order of magnitude) across the tuning range of the device. A consequence of this variation in tuning efficiency is that mode jumps in the tuning space of the laser may not be distributed linearly with drive current, which can cause problems for a calibration algorithm that is attempting to find the operating points of the laser with high mode purity.

A direct and accurate approach to measuring the tuning efficiency of a device (or to map the frequency output of the device) is to increment the section current(s) with which frequency changes and to accurately measure the frequency at each point. A drawback of this approach, as described in "Fast Accurate Characterisation of a GCSR laser over the complete EDFA Band" *Tom Farrell et al. LEOS'99 November, San Francisco,* is that for certain device types, the tuning efficiency at low coarse tuning section current is very high, forcing a particularly low step size for this section. For example in the DBR (Distributed Bragg Reflector) laser, the tuning efficiency will be very high at low DBR passive section current. To apply this low step size over the entire operational range of the DBR section is time consuming. In production environments this approach is generally too inefficient to be commercially viable. Another drawback of using a single step size over the operational range of the section current is that, since the data measured is varying non-linearly, a characterisation algorithm searching for features in the data (such as the mode boundaries) must find a means of coping with this non-linear variation.

It is known that the output power of a device will fall off as the current in the passive sections is increased. Thus

for measurements taken at fixed gain section current, the operating points may not fall within the required range of specified power outputs. Thus combining a series of measurements at different fixed gain currents, where the passive section currents are ramped as before, may be needed to produce the final set of operating points satisfying all the power, frequency and mode purity (SMSR) requirements. This of course adds extra time and analysis to the process, again an important issue in assessing the viability of a method for use in production environments.

There is therefore a need to provide a method that enables a compensation in the variation in tuning efficiency and power of the laser diode to be effected.

Object of the Invention

It is an object of the present invention to provide a method for efficiently compensating for variation in tuning efficiency and power of a laser diode.

Summary of the Invention

Accordingly the present invention provides a method of compensating for variation in tuning efficiency and power of a multi-section tuneable laser diode. The methodology and technique of the present invention is advantageous in that it is generic and can be applied to several types of tuneable lasers such as DBR, SG-DBR, SSG-DBR, GCSR etc..

In a preferred embodiment the invention provides a method of normalising the output values of a laser diode, the comprising the steps of varying the control currents for a specific section of a laser diode device over a range of values in a first sample index so as to obtain a set of output values for that section of the laser diode,

normalise the set of output values, such that the normalisation of the output values compensates for non-linearities in the output values by effecting a change in relationship between the control currents and the sample index.

The output values are desirably representative of power or frequency.

The method may be further used to obtain sets of normalised values for one or more further sections of the laser.

The normalisation is desirably effected by a transform applied to the sample index, the application of the transform changing the control currents and the output values. The transform is typically a non-linear transform.

The generated transform may be subsequently used to effect the generation of a further set of output values for multiple combinations of control currents or sections for the laser device, the generated set having being normalised due to the utilisation of the transform.

In one embodiment, the normalisation of the output values is effected using the current of the mode jumps.

The mode jumps are typically detected by a power measurement, and are more typically detected by an observation of discontinuities in a power measurement.

In an alternative embodiment the mode jumps are detected by a frequency measurement, and in such an embodiment are typically represented by a step in a frequency measurement.

The application of the transform may be used to effect an equalisation of mode width.

The method may be further used to determine deviations in mode width, thereby providing indications of the integrity of the laser device.

The normalisation may be effected using a relative loss of that section as a function of control current. The gain current of the laser device can be altered using said normalisation.

The normalisation of output values may be used to provide for a determination of location of modes.

The method may include the further step of determining suitable operating points, the operating points being selectable on the basis of a determination of a mid-point in frequency values for a specific mode. The operating point is typically at the mean frequency for that mode and benefits from maximum side mode suppression.

The modes are desirably locatable by effecting a differentiating of the normalised values.

The invention also provides for a method of determining a mode width for a laser diode device, comprising the steps of: determining the location of the modes, extracting from the determined mode locations, the mode width in control current as a function of a control current for all modes and all currents so as to provide for a relationship between the mode width of the laser and a control current for that laser, and converting the control current to frequency for the device so as to provide a relationship between mode width and frequency.

The inventions also provides for a method of obtaining the mode modulation of laser diode, the method comprising steps ofobtaining tuning characteristics of a tunable laser and measuring a set of samples where this data has been normalised out, detecting mode jumps of the laser, measuring the mode width of the laser and plotting this value against a predetermined combination of the control currents where this mode is present which can in turn be converted to output frequency of the tunable laser, andconverting the mode width to a percentage deviation of average mode width of the laser

These and other features of the present invention will be better understood with reference to the following drawings.

Brief Description of the Drawings

Figure 1 is a schematic drawing of a known laser diode,

Figure 2 is a schematic showing a conventional wavelength measuring apparatus,

Figure 2a shows the output power of a device at uniform current intervals in the direction that the tuning efficient variations are to be suppressed,

Figure 2b shows the output power range of Figure 2a, but with the effects of the tuning efficiency variation suppressed,

Figure 3 shows a high-resolution power line as taken along a full range of DBR passive current sections and at a constant phase current and also indicates the position of mode jumps,

Figure 4 is a graphical representation of a polynomial correction tuning efficiency approximation, according to the present invention

Figure 5 is a graphical representation of polynomial scaled to a desired sample and current range according to the present invention

Figure 6 is an example of a linear power plane,
Figure 7 is an example of a non-linear power plane over the same range of values as Figure 6, as provided by the methodology of the present invention,
Figure 8 is a plot of mode width verses bragg current for a laser diode device with mode modulation,
Figure 9 is a plot of mode width variation verses frequency for a laser with mode modulation,
Figure 10 is a normalised version of the plot of Figure 9 with the % mode width variation converted to frequency modulation,
Figure 11 is an intensity map of power vs two control currents of a tunable laser mapped onto a Power vs. Total control current map, Figure 12 shows a plurality of curves representing the loss of the front and back gain currents for a plurality of different gain currents, and
Figure 13 is a plot of gain current verses front and back current showing the required ratio between the parameters required to effect a desired power level for the device

Detailed Description of the Drawings

The present invention provides a method of compensating for inefficiencies in tuning and power of a laser diode, specifically a multi-section tuneable laser diode. The technique is generic and can be applied to several types of tuneable lasers such as DBR, SG-DBR, SSG-DBR, GCSR etc., although for ease of explanation it will now be described with reference to application to a DBR tuneable laser. It will be appreciated by those skilled in the art that this illustration is exemplary of the methodology of the present invention and it is not intended to limit the application to any one specific laser diode type.

The techniques used by the method of the present invention enable the formation of a set of output values, typically a power or frequency plane, which will be understood to be a series of power or frequency measurements at section current combinations within a specified range. Using the technique of the present invention it is possible to provide for a more evenly spaced distribution of modes in the resultant data set which is advantageous in that it enables simpler and more effective analysis techniques. The method of the present invention also provides for a reduction in the size of the data set that requires analysis, thereby providing a more time and processing efficient system.

The methodology of the present invention will now be described with reference to a three section DBR type laser device. Firstly, a method to obtain the characteristics, preferably the tuning efficiency as provided by the frequency or power output, of the laser according to the present invention will be described. Using the resultant data set, the invention then provides for a technique to use this data and measure the characteristics of the laser while cancelling out the tuning efficiency variation and the power loss due to increasing currents in the passive sections. An exemplary application of the technique will then be described with reference to a specific device

1. Automated Approximation of Laser Tuning Efficiency:

As detailed above. the present invention provides a methodology to determine a function to approximately map the tuning efficiency of the laser. It should be noted that according to the present invention, the tuning efficiency function is only required to determine a suitable set of sample to section current mappings; consequently the tuning

efficiency itself is not required to any great accuracy, but it will be appreciated can be obtained accurately from measurements described in this patent, and moreover measurements over a subset of the current space of the tunable laser are sufficient. This it will be appreciated provides for a time-efficient technique. For example, within a DBR laser, this subset would span the range of the DBR passive section current only, with the phase section current set at a constant value.

Although the present invention is not intended to be limited to any one specific theory or methodology it will for purpose of discussion be assumed that all that is needed to form a reasonably accurate approximation to the tuning efficiency of any device is the location of each mode jump of interest and the further assumption that frequency change across each jump is approximately uniform. To obtain each mode jump, a straight line is defined across passive section current space, which may be a function of one or more section currents. A series of power measurements is obtained along this function over small increments in current. The data is then discretely linearly filtered and thresholded to extract each mode jump.

This information, combined with the assumption that the frequency change across each mode jump is uniform, enables the mapping of approximately uniform steps in frequency to non-uniform steps in section current. If one has access to frequency data, however, or to a measure that varies in proportion with the frequency across the subset of section currents of interest, this may be utilised to form an equivalent mapping. As a result, it will be appreciated that the extraction of mode jump locations may not always be required.

Each set of discrete mappings or transforms is plotted for each contributing passive section. Since each plot consists of discrete value mappings, one may choose to either interpolate between defined mappings or to define a continuous function, which, in a least squares sense, fits the defined mappings optimally. The user may then specify the subsection of currents which are of interest and the amount of power plane samples which are desired within that region. Each passive section function can then be scaled accordingly, and the resulting mappings used to define locations in section current which correspond to each power plane sample. The resulting power plane is then predominantly free of the effects due to tuning efficiency variation.

2. Use of Non-Linear Power Planes:

This method has been developed as the first step in a tunable laser calibration system, and is specifically adapted to compensate for the variations on output power of the device due to increasing losses in the passive sections which is cause by increasing the control currents of the laser so as to provide for the modes jumps to be represented by similar jumps in output power of the device, and thus more easily determined. The system calibrates each device based upon power/frequency measurements obtained at section current combinations within a pre-defined range of currents. It will be appreciated that the system and methodology is not device specific, although, as stated above, the straight line over which mode frequency changes occur will vary in terms of the section currents from device to device . It will be understood therefore that for some devices, for example a SG-DBR type laser, non-linear power sampling may be required across more than one section current. In figure 14 a power plane for an SG-DBR laser is shown. A supermode is selected and the centre of regions

where the output power has no mode jumps is selected and these points are denoted by dots. If as for a DBR laser the current at which these points occur is plotted against the mode index the graphs Figure 15 and Figure 16 are obtained for the Front and the Back sections of the laser. These represent the tuning rates of these sections and can be used in a similar way to that shown for the DBR laser.

It should be noted that a similar method can be used for a phase section of a laser also by plotting the position of a mode as a function of phase current and using a non-linear sampling rate to cancel any non-linear tuning of the phase section when measuring multiple planes.

Benefits of Removing the Effects of Tuning Efficiency

Variations: The main benefit of removing the effects of tuning efficiency variations across the device, is to maximise the efficiency of a subsequent calibration algorithm with regard to the fact that each mode is represented by a uniform amount of points in the power plane, and that number is set as low as possible without compromising accuracy, i.e. that no mode is represented by too many or too few points. The advantage of the technique of the present invention is evident from a comparison of Figures 2a and 2b.

Fig. 2a displays the output power of a device at uniform current intervals in the direction that tuning efficiency variations are to be suppressed (linear power line). Fig. 2b displays the output power across the same range, but with the effects of tuning efficiency variation suppressed (i.e. a non-linear power line as provided by the technique of the present invention). It will be appreciated that a

mode jump should be distinguishable by a discontinuity in power or frequency. It will be apparent from an inspection of the two Figures, that there is a large variation in the distance between mode jumps in the linear line relative to the non-linear line (Figure 2b). Although both lines contain the same amount of power samples, it is clear that there are not enough samples in the linear line to easily extract important signal characteristics at low currents. However, the equivalent data in the non-linear power line is easily extractable.

Another benefit of removing the effects of tuning efficiency variations across the device is that each point midway between two mode jumps (an instance of which is marked as the vertical line X-X in Fig. 2b) will also be the centre of its tuning range. This means that the point will be at the mean frequency for that mode, and will benefit from maximum side mode suppression. This makes it an ideal choice as the operating point for that mode.

Measuring Frequency Modulation of a Laser using Mode Widths

As described previously the mode width (in current) at relative tuning currents in the laser describes the relationship between tuning rate and current(GHz/mA). It will be appreciated that the Mode Width is proportional to tuning rate vs. tuning current, which can be understood in terms of the Bragg current as meaning that the width of the mode in Bragg current is the relative size of the reflection peak that is causing the laser to operate at this frequency relative to the adjacent modes of lasing of the laser.

Using this relationship it is possible to obtain a plot of mode modulation of the laser. Mode modulation is caused by

extra Fabry Perot cavities existing in the laser and is normally due to an undesirable reflection at the interface between the individual sections of the laser. These reflections when added to the desired reflections from the Bragg etc.. cause a modulation in the mode width of the laser.

The example below is shown for a DBR laser but the same method can be equally applied to any type of tunable laser.

From a plot of DBR power (where the tuning currents have been normalised out, such as that shown in Figure 7) a plot of the mode jumps of the laser can be obtained by using differentiation and a threshold to obtain where steps in power occur. These steps in power represent the mode jumps of the laser and are shown in Figure 17

From this plot (Figure 17), if the mode jump width (in Bragg Current) is extracted as a function of Bragg current (where Bragg Current is the current in the middle of the mode where each mode width is measured) for all modes and all phase currents and a plot, such as that shown in Figure 8, is obtainable which provides for a graphical representation of the mode width of the laser vs. Bragg Current. As can be seen from the graph of Figure 8, this is a very uniform result and shows that the mode modulation is dependent directly on the Bragg current of the laser. This can be related directly to Frequency by converting Bragg current to Frequency with the aid of a plot of the tuning rate of the Bragg Section. Such a plot is shown in Figure 9 and can be obtained by some wavelength measurements such as a wavelength meter or equivalent or, as previously described by obtaining a plot of mode position vs Bragg current and sampling some frequencies either using a wavelength meter or using the setup as in Figure 2.

The plot of Frequency vs. Bragg is true for any points on all lines in-between each adjacent mode jump. As the laser has mode jumps the tuning away from each of these lines will be slightly different and a factor is required which is the relative frequency tuning range of a single mode of the laser for a fixed phase current. These values change from device to device but an exemplary DBR laser device may have values of the order of 12GHz and the cavity mode jump is 70GHz. Therefore, the factor we require is 12/70. If we multiply the frequency variation plot from above by this factor the frequency modulation of the device is obtained versus the absolute frequency of the laser. This is a relative value and shows deviations from the ideal uniform performance of the laser.

In Figure 10 the mode modulation is caused by a reflection between the gain section and the phase section of the laser and the period of modulation is approximately 125GHz. This corresponds to a cavity length in the device of approx 340 μm which is as expected.

This measurement is a very good detector of internal reflection in the tunable laser and can be obtained from a simple power plane of a tunable laser. This measurement is fast and can be used in the characterisation of tunable lasers in a production environment. As the result obtained can be easily thresholded to detect when the internal reflections are too large the device will not meet the required specification it is ideal for Pass/ Fail criterion required in an automated production system.

<u>Measuring Power Loss Due to Increasing Currents in the Passive Sections:</u>

All tunable devices suffer power loss due to increasing currents in the passive sections. An objective of device calibration is to not only obtain operating points at pre-defined frequencies within the device band, but to ensure those points are of a certain output power level. Based upon an assumed relationship between power loss and passive section currents, the input gain current may be increased in such a way as to counter the loss.

The example below is for an SG-DBR laser but applies equally for a DBR laser, GCSR, SSG-DBR and other multi-section tunable lasers.

If a coarse measurement of output power is measured on an SG-DBR laser and the output power is plotted against front current plus back current then a graph such as that in figure 11 is obtained.

This shows how the output power of the device varies as a function of the passive current (excluding the phase current). If this plot is curve fitted to obtain the median output power (or some such other method is used such as averaging as shown in the figure 12) a curve which represents the loss of the front and back sections is obtained. If this is repeated for different gain currents a set of these curves can be obtained as in figure 12.

It is possible then, using this information, to select the output power required to operate the laser. This selected power will cut or bisect several of the curves obtained at each gain current in Figure 12. By plotting the gain current value from each curve against the front and back current value, a plot of gain current vs. Front and back current is obtained for the required output power value as

shown in Figure 13. This plot enables determination of the ratio between front and back current verses the gain current required to obtain the required power level. This can be fitted with a linear or higher order polynomial or such method to get the relationship and a power plane can be re-measured where the gain current at each point on the plane is adjusted according to this relationship. This results in a power plane which will typically have 2dB of power variation as opposed to the 6dB for the case where the gain current is kept constant.

Using this technique to reduce the output power variation of a tunable laser measurement plane enable power equalisation to be obtained in a much easier fashion as a large part of the power variation has already been compensated for. Also this allows easier detection of changes in the power level which denote mode jumps of the laser. As the power variation is reduced the variation in these jumps of power will be similar in size and allow easier detection.

3. Example:

The techniques of the present invention described above will now be described with reference to an example of tuning efficiency approximation for a DBR tunable device. As was shown in Figure 1, this is a three section device, with two passive sections, phase and DBR, and an active section, gain. In this particular type of device, mode jumps tend to occur with increasing DBR passive section current. Hence, a high-resolution power line was taken along the full range of DBR current and at a constant phase current (Fig. 3), and the location of mode jumps identified.

As shown in Figure 4, this data may be used to plot a DBR current versus frequency index relationship (each unit increase in value represents a uniform jump in frequency). A 2^{nd} order polynomial function was then fitted to this data, bound by its upper and lower limits. Both the original data and the fitted polynomial function are shown in Fig. 4. The fitted function for the specific data set illustrated is defined below:

$$f(x) = 0.1123x^2 + 0x + 0.0366, \quad (1)$$

where x is the frequency index of the data. This it will be appreciated is a standard quadratic polynomial which maps uniform steps in frequency to non-uniform steps in section current across the full range of the device. In order to perform a full characterisation of the device, a subset of this entire range, i.e. a region of specific interest in both passive sections is then specified, along with a desired power plane size: i.e. how many data points are required for a specific range of currents. This range may be specified in terms of the maximum and minimum currents (I_{high} and I_{low}). Using a specific example of utilising 300 power samples on the DBR passive section in the range between 0.99 and 45.09 mA inclusive, it is possible to transform the fitted function, defined by equation (1) into a sample index to section current value mapping, based upon this specified data. The function transformation is defined below (equation (2)), and it will be appreciated that the present invention is not intended to be limited to any specific values or polynomial function. It will be further noted that $f^{-1}(I_{low})$ is x at $f(x) = I_{low}$, and that the equivalent stands for $f^{-1}(I_{high})$ (see Fig. 3 for the mapping between each x value and I_{low} & I_{high}).

$$f(s)=\left(a\times\left(\frac{m}{k}\right)^2\right)s^2+\left(\left(\left(2\times a\times f^{-1}(I_{low})\right)+b\right)\times\frac{m}{k}\right)s+\left(\left(a\times f^{-1}(I_{low})^2\right)+\left(b\times f^{-1}(I_{low})\right)+c\right)$$

(2)

where: a = x^2 coefficient in $f(x)$.

b = x coefficient in $f(x)$.

c = offset in $f(x)$.

I_{low} = the lower threshold of the passive section current region of interest.

I_{high} = the upper threshold of the passive section current region of interest.

$m = f^{-1}(I_{high}) - f^{-1}(I_{low})$.

k = No. of sample periods across mapping range.

s is the sample index.

Substituting the values specific to this example for the above, yields the polynomial defined in Equation (3) below, and plotted in Fig. 5:

$$f(s)=0.00037s^2+0.03741s+0.9872 \quad (3)$$

The solving of this polynomial maps each of 300 sample points to a section current within the specified range, based upon the original mapping function, $f(x)$ (equation 1). Since tuning efficiency does not vary significantly with phase section current, the mapping between sample index and section current remained linear, and hence a uniform step size was used between power samples. It is now possible to utilise the sample index to current mappings for each passive section in the measurement of a power plane.

Shown in Figs. 6 and 7 is a comparison between a 300 × 300 linear power plane over the range of DBR currents described by the function of equation (3) and shown in Fig 5, and a non-linear plane over the same range of currents. The plane

of Figure 6 is formed using conventional techniques such as those described in *"Fast Accurate Characterisation of a GCSR laser over the complete EDFA Band" Tom Farrell et al. LEOS'99 November, San Francisco,* whereas that of Figure 7 is formed using the technique of the present invention. The relative uniformity of the width of each mode in the non-linear plane (Figure 7) is apparent especially when compared to the linear plane (Figure 6).

It will be appreciated that the specific example utilising a DBR type laser device enables the power plane characterising the device to be effected on a single measurement set. In application of the technique to other laser types it will be appreciated that several measurements may be required to fully characterise the device. For example using a SG-DBR device it is necessary to measure the output power vs. all of the coarse tuning currents, and for a 4-section SG-DBR laser this results in a plane. These measurements are repeated as a function of any other tuning sections that the device may have. For example with an SG-DBR laser several planes are measured of Front grating vs. Back grating against phase current.

It will be appreciated by those skilled in the art that although the example of the present invention has been described with reference to specific mathematical equations and techniques that many alternative techniques may be utilised to obtain the same effect or implementation as that provided by the specific example herein illustrated.

It will be understood that the present invention provides for a method that compensates for tuning efficiency in a laser diode device. By providing a technique that enables a different sampling rate to be applied in different regions of interest in the power plane of the device.

It will be appreciated that the present invention provides for the provision of a graph of the relative tuning rates of a section of a multi-section tunable laser by finding the relative positions of modes in the laser. According to the present invention the mode widths can be used to get mode modulation of a tunable laser. By effecting a change in the gain current while measuring a power plane for a laser is it possible, according to the present invention to compensate for power variation due to absorption in the passive sections of the laser. The present invention additionally provides for the measurement of a plane which is adapted takes all of the above into account and compensates for the resulting in a measurement plane where either the relative size of modes is constant or the power jumps due to mode jumps are equalised.

The words "comprises/comprising" and the words "having/including" when used herein with reference to the present invention are used to specify the presence of stated features, integers, steps or components but does not preclude the presence or addition of one or more other features, integers, steps, components or groups thereof.

Claims

1) A method of normalising the output values of a laser diode, the method comprising the steps of:

a) varying the control currents for a specific section of a laser diode device over a range of values in a first sample index so as to obtain a set of output values for that section of the laser diode,

b) normalise the set of output values, and

wherein the normalisation of the output values compensates for non-linearities in the output values by effecting a change in relationship between the control currents and the sample index.

2) The method as claimed in claim 1 wherein the output values are representative of power or frequency.

3) The method as claimed in claim 1 or 2 further comprising the step of obtaining a set of normalised values for one or more further sections of the laser.

4) The method as claimed in claim 1 wherein the normalisation is effected by a transform applied to sample index, thereby changing the control currents and the output values.

5) The method as claimed in claim 4 wherein the transform is a non-linear transform.

6) The method as claimed in claim 4 or 5 wherein the generated transform is subsequently used to effect the further generation of a set of output values for multiple combinations of control currents or sections for the laser device, the generated set having being normalised due to the utilisation of the transform.

7) The method as claimed in claim 1 wherein the normalisation of the output values is effected using the current of the mode jumps.

8) The method as claimed in claim 7 wherein mode jumps are detected by a power measurement.

9) The method as claimed in claim 8 wherein the mode jumps are represented by discontinuities in a power measurement.

10) The method as claimed in claim 7 wherein mode jumps are detected by a frequency measurement.

11) The method as claimed in claim 8 wherein the mode jumps are represented by a step in a frequency measurement.

12) The method as claimed in claim 4 wherein the application of the transform effects an equalisation of mode width.

13) The method as claimed in claim 12 further comprising the step of determining deviations in mode width, thereby providing indications of the integrity of the laser device.

14) The method as claimed in claim 1 wherein the normalisation is effected using a relative loss of that section as a function of control current.

15) The method as claimed in claim 14 wherein the gain current of the laser device can be altered using said normalisation.

16) The method as claimed in claim 1 wherein the normalisation output values provides for a determination of location of modes.

17) The method as claimed in claim 16 further comprising the step of determining suitable operating points, the operating points being selectable on the basis of a determination of a mid-point in frequency values for a specific mode.

18) The method as claimed in claim 17 wherein the operating point is at the mean frequency for that mode and benefits from maximum side mode suppression.

19) The method as claimed in claim 16 wherein the mode are locatable by effecting a differentiating of the normalised values.

20) A method of determining a mode width for a laser diode device, the method comprising the steps of:

a) determining the location of the modes,

b) extracting from the determined mode locations, the mode width in control current as a function of a control current for all modes and all currents so as to provide for a relationship between the mode width of the laser and a control current for that laser, and

c) converting the control current to frequency for the device so as to provide a relationship between mode width and frequency.

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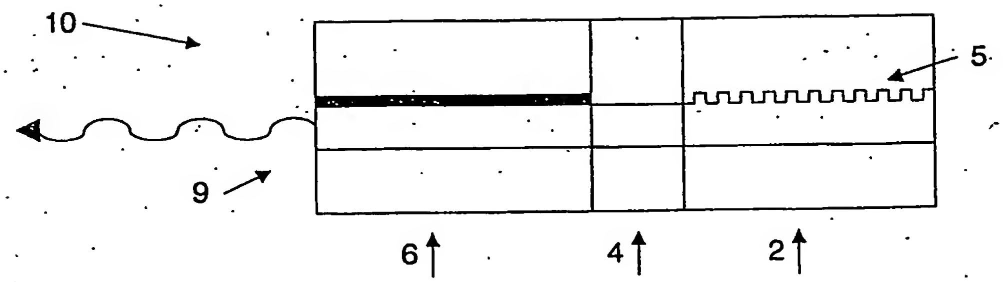

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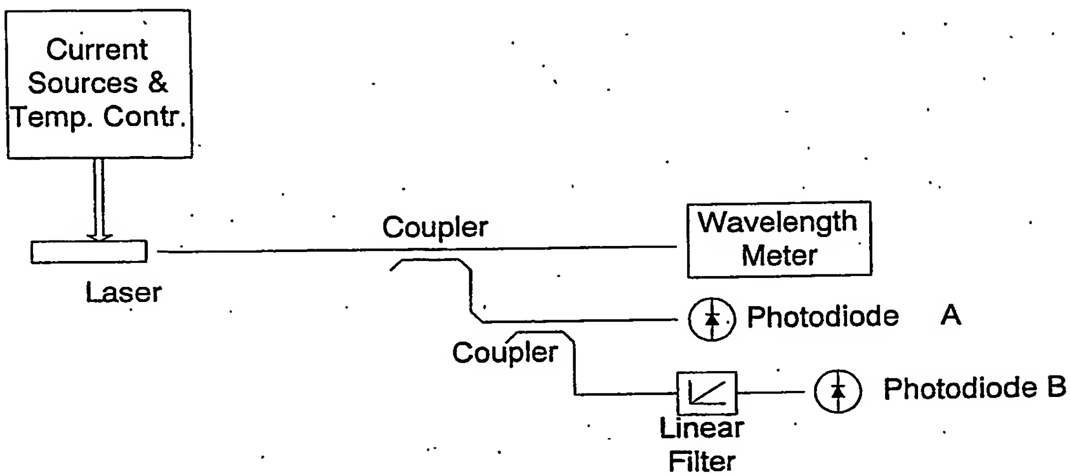


Figure 2

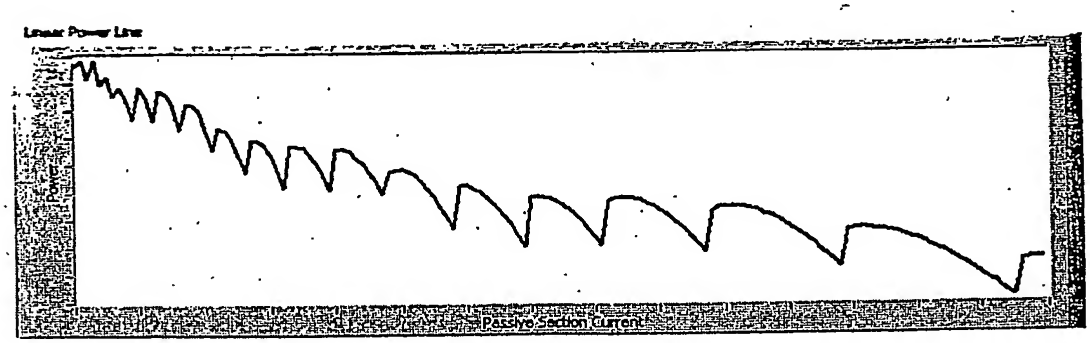


Figure 2a

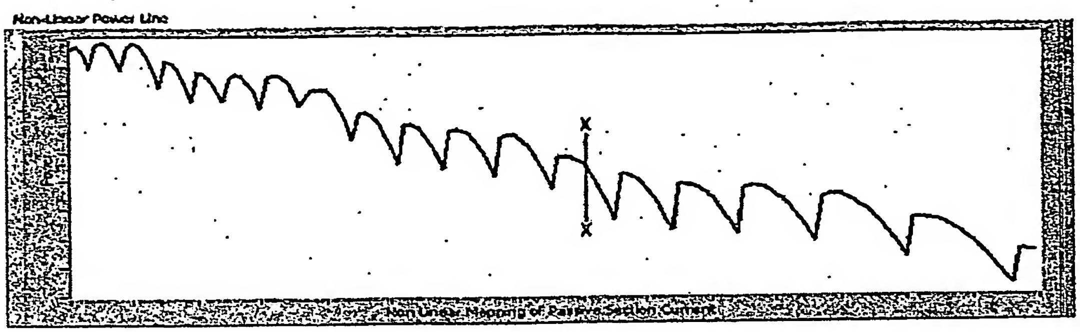
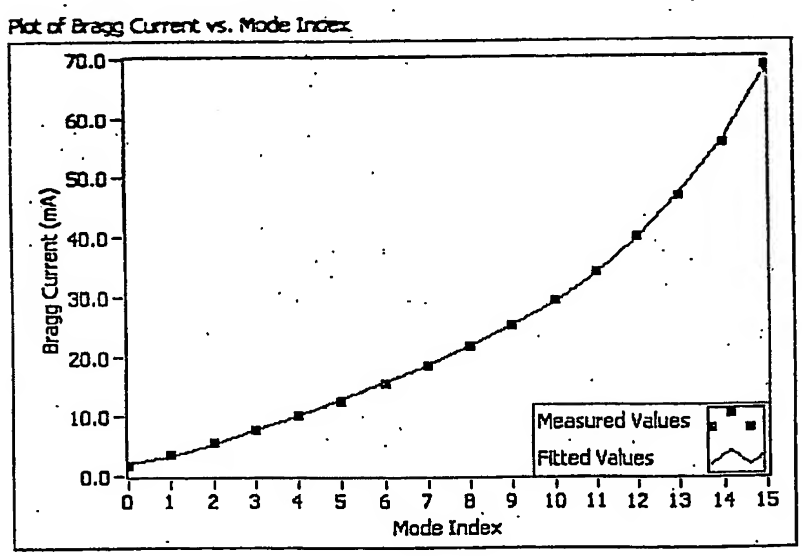


Figure 2b

Figure 3



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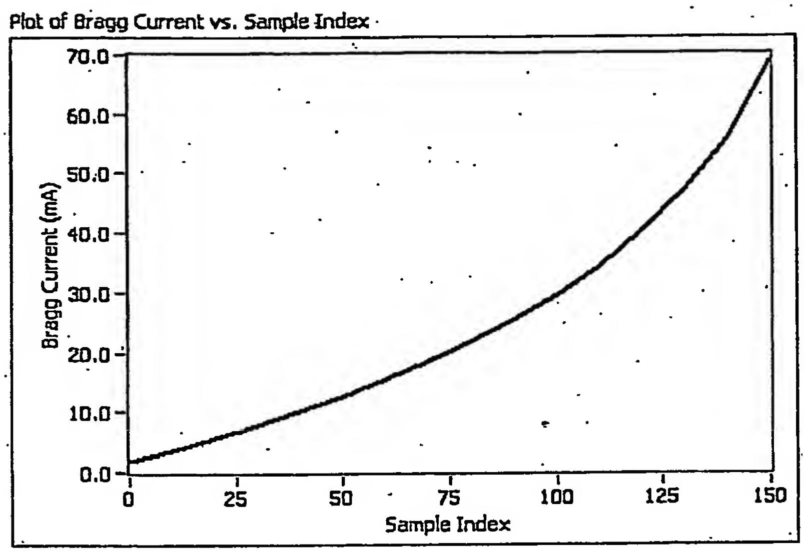

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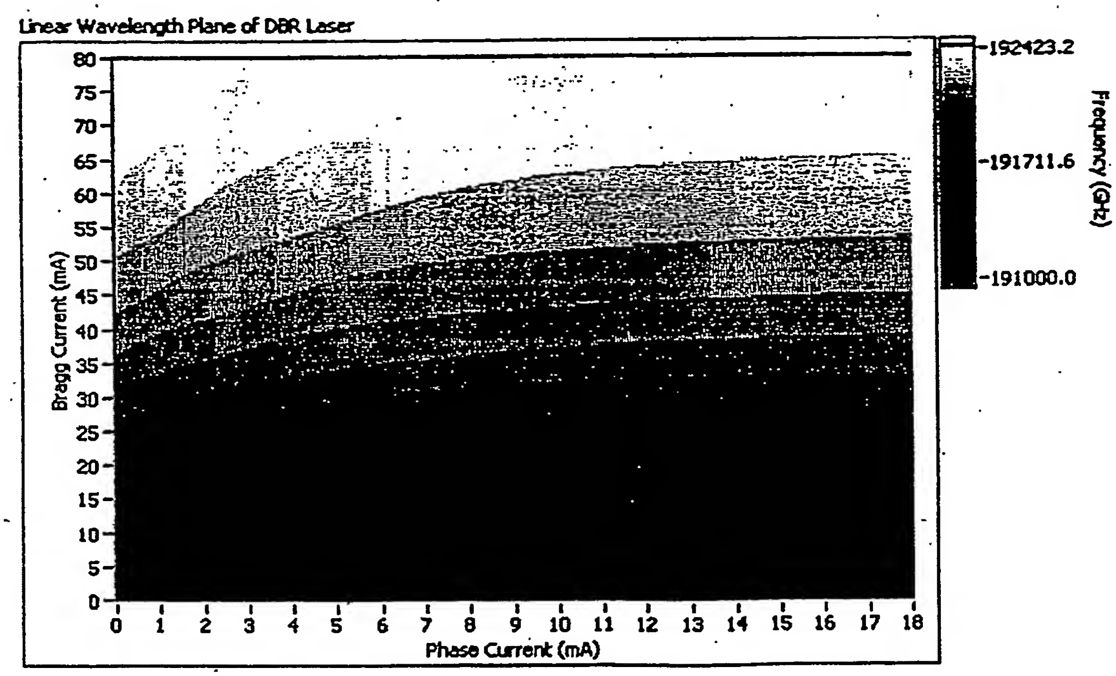

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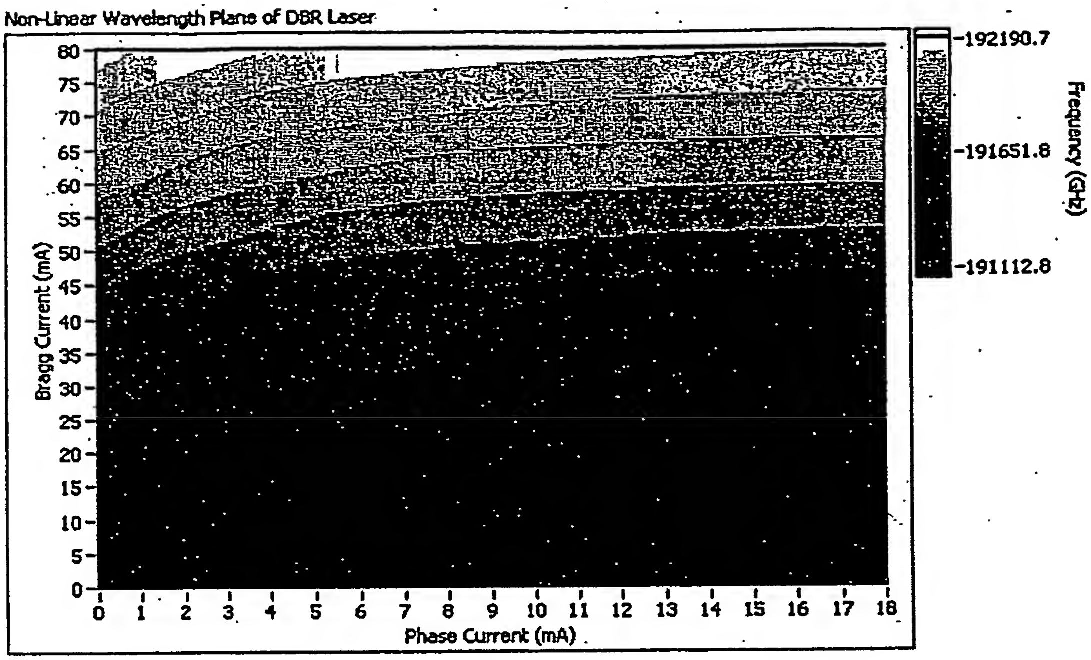

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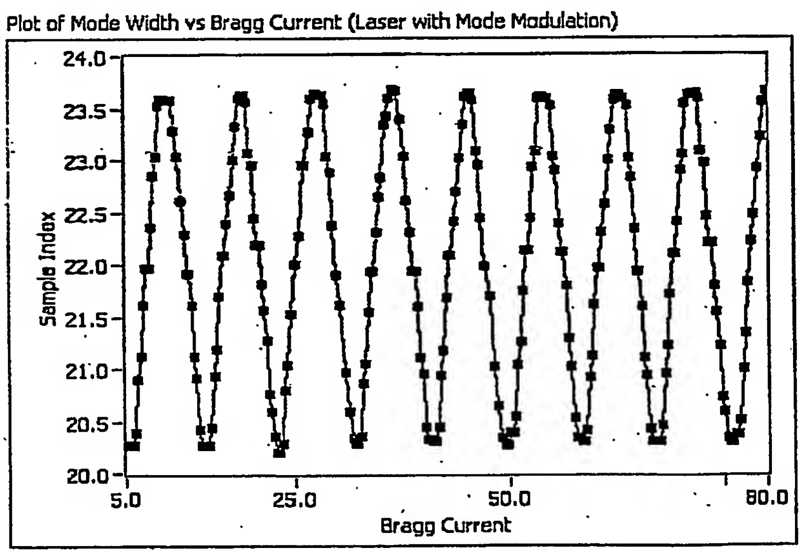

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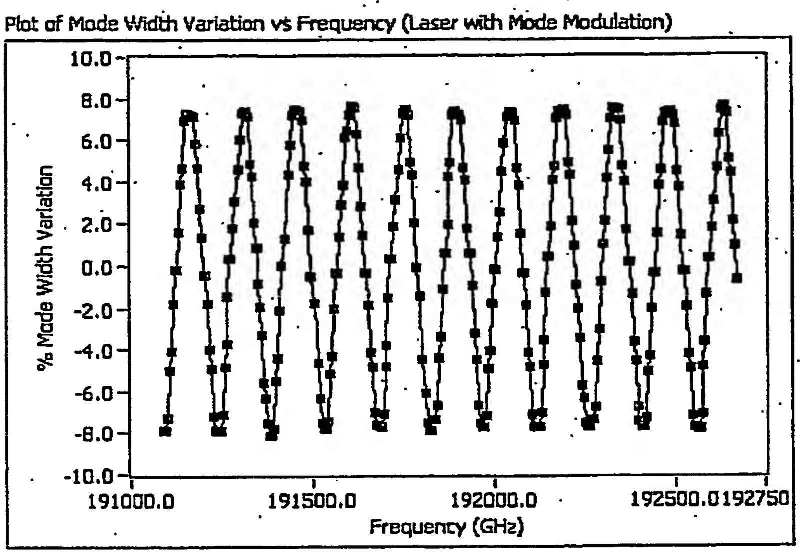

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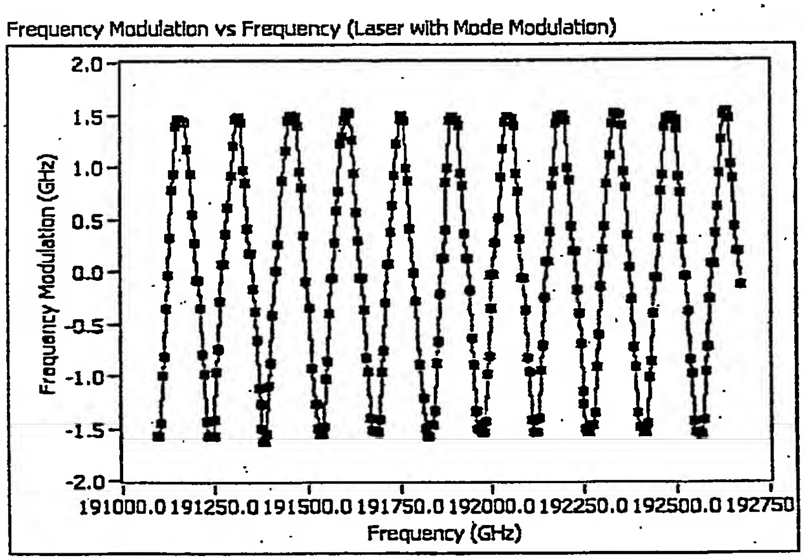

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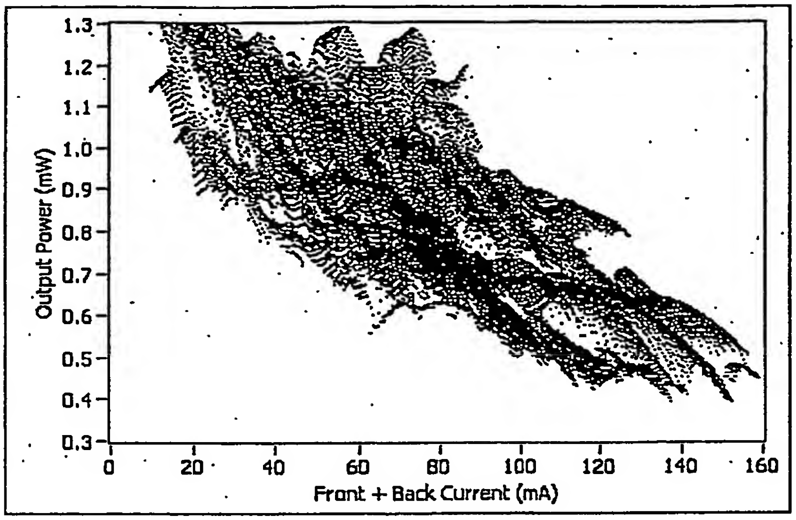

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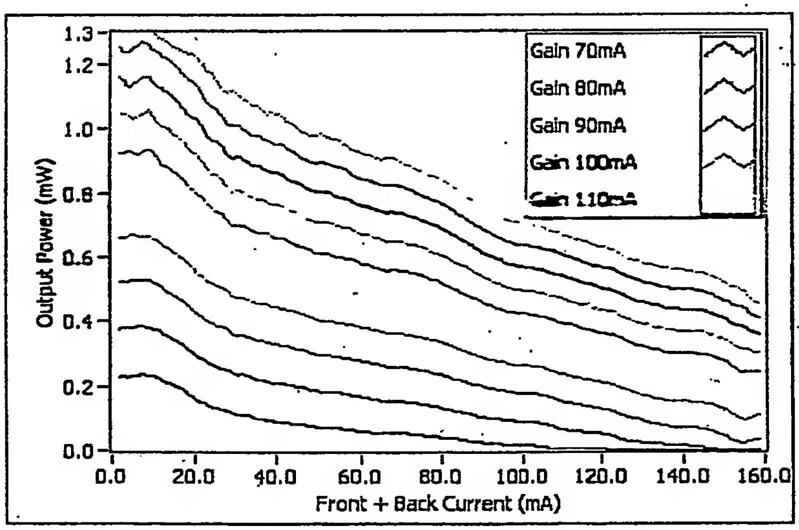

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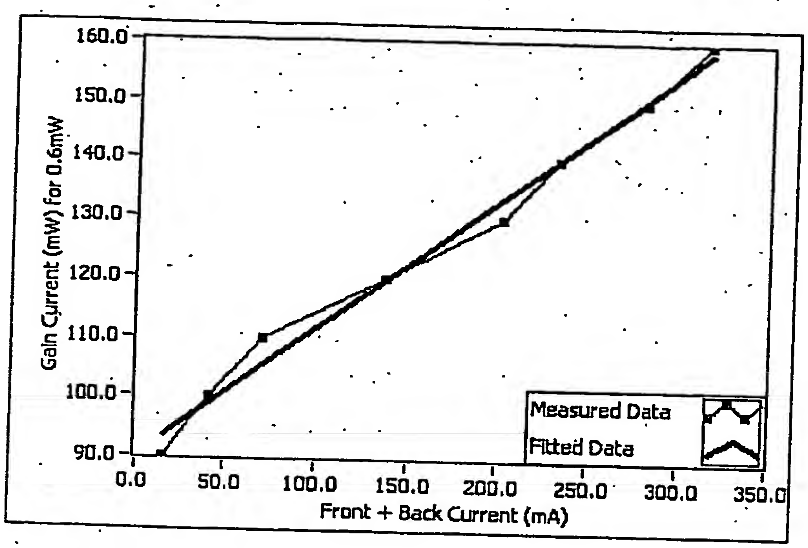

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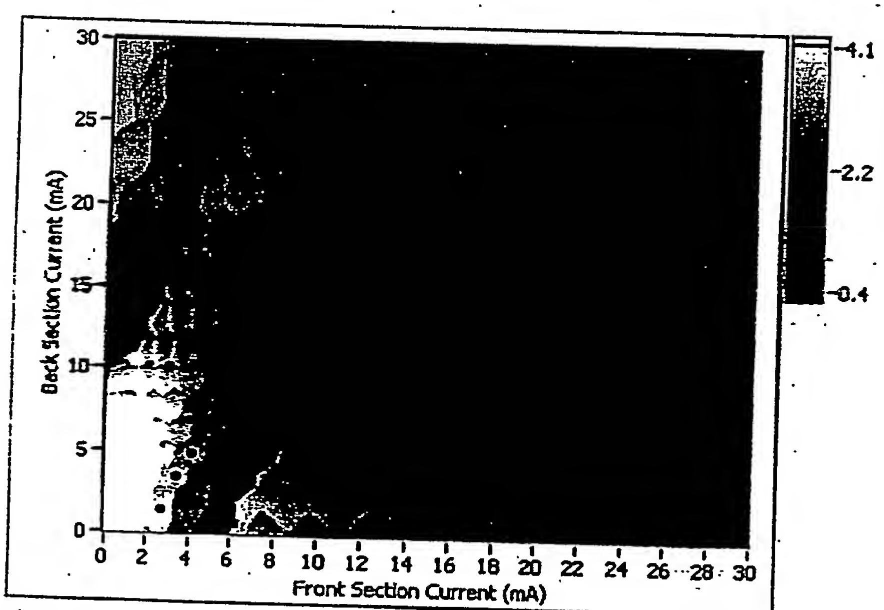

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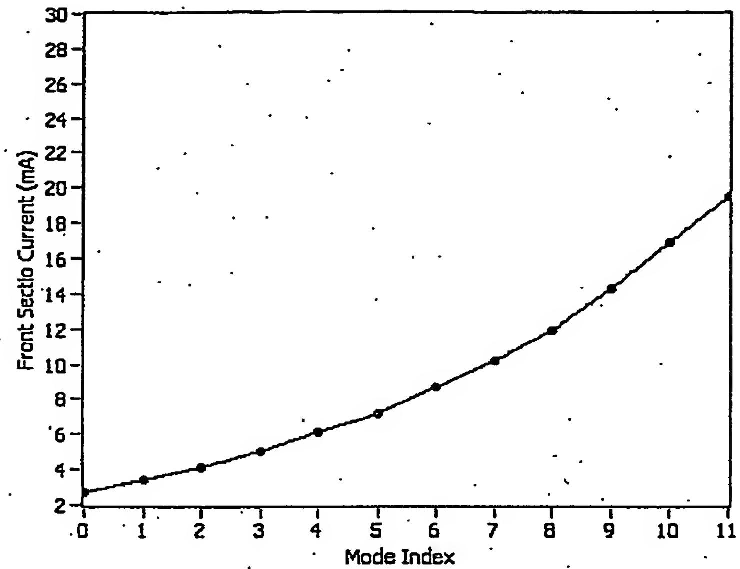

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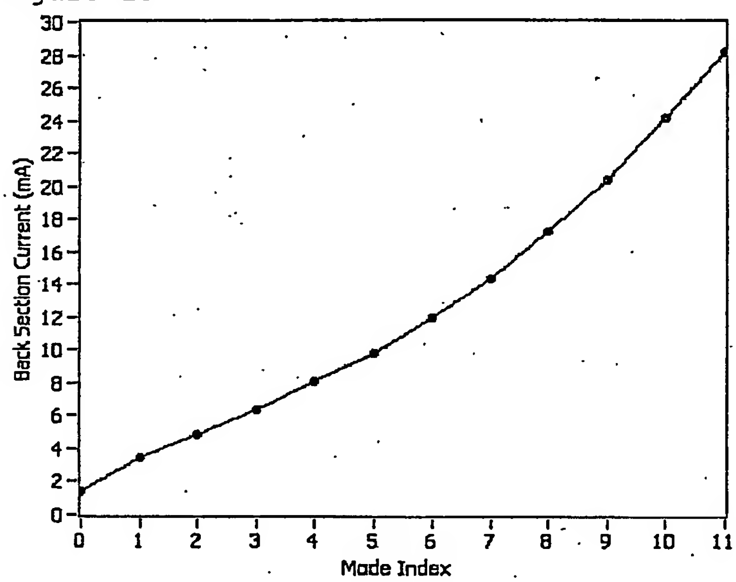

Figure 16

Plot of Mode Jumps of DBR Laser

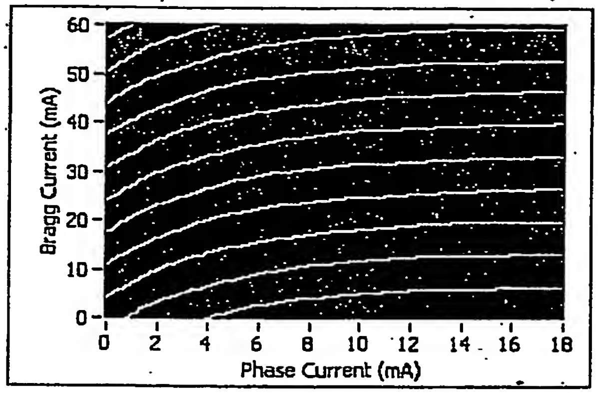

Figure 17

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